Design considerations and performance of 1kHz KrF excimer lasers for DUV lithography

Richard G. Morton, Igor Fomenkov, William Partlo, Palash Das, Richard Sandstrom

Cymer Laser Technologies
16275 Technology Drive, San Diego, CA 92127

ABSTRACT

The operation of 1 kHz KrF lasers for DUV Lithography applications requires a design which minimizes perturbations to the optical and electrical properties of the gas present, at one millisecond intervals, in the lasing region and vicinity. The optimum design results from a compromise between electrical and fluid dynamic requirements, since these cannot be simultaneously fully satisfied. Other constraints on a commercially viable design are those rooted in issues such as manufacturability, safety, cost, compatibility with fluorine, and service lifetime of the resulting structure. CYMER$_{®}$ has successfully engineered a laser which produces linear average power output scaling with pulse repetition rates to 1 kHz at a line-narrowed bandwidth of < 0.8 pm. The stabilized pulse energy is 10 mJ with a FWHM of ~ 15 nS, producing an average power of 10W at 1 kHz pulse repetition rate. The 3σ value of pulse energy stability is 5%. In addition, the chamber exhibits low fluorine consumption and a lifetime in excess of 2 billion shots. Measured performance data are presented along with a general system layout and facilities requirements.

Keywords: High pulse rate industrial KrF lasers, deep ultraviolet photolithography

2. INTRODUCTION

Rapid developments in optical delivery systems for DUV lithographic steppers and scanners have driven the demand for higher pulse repetition frequency (PRF) KrF lasers which operate at a wavelength of 248 nm. The basis of this demand is the requirement for higher product throughput and increased dosage accuracy. In response to market requirements for increased PRF devices, Cymer has developed a 1kHz laser through the application of technology advances to its previous product. The new, 1kHz (5000 series) systems retain the advantages of all-solid-state pulse power[1] and produce essentially the same spatial, spectral and temporal output beam properties as their lower PRF predecessor.

3. DESIGN CONSIDERATIONS

The principles pertaining to electrode surface profile design for producing a well-defined discharge channel are well understood. This well-defined channel results in a similarly well defined laser beam intensity distribution, which is a necessity in DUV lithographic applications. The electrodes are generally shaped to concentrate the electric field on the axis of the laser optical cavity and to avoid parasitic arc-overs in other areas.

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In order to run the laser at high PRF, it is necessary to replace the gas in the discharge region of the chamber in the time between pulses so that the laser medium will be free of optical and electrical inhomogeneities. This is required in order to generate pulses with a high degree of repeatability, both in energy content and spatial intensity profile. Replacement of the gas in an interpulse time becomes generally more demanding on the blower system as the operating PRF is increased. Higher gas velocities require increased power input to the blower system and result in higher mechanical stresses on the fan, motor, bearings, and other drive train hardware. Several hundred Watts of electrical power are typically required to drive the blower system in high PRF KrF lasers, which operate at gas pressures of several atmospheres.

The principles for efficient wind tunnel design are also well understood, and if followed result in minimum levels of turbulence, electrical motor power demand, and stress on mechanical components. The optimum gas flow design allows generation of the velocities needed for high PRF operation of the laser at a practical electrical input power, and leads to extended service lifetime of the moving mechanical components of the chamber assembly.

A problem arises in the design of high pulse repetition rate KrF lasers in that the electrical and fluid dynamic requirements cannot be simultaneously optimized in a practical structure with long service life. On one hand, the electrode shapes which produce the best discharge channel are not those which lead to efficient, laminar gas flow. On the other hand, the electrode surfaces which form the gas flow channel cannot be shaped for efficient gas flow because they would then fail to produce a suitable discharge shape. A compromise must therefore be reached which achieves an overall optimal internal structure of the laser chamber.

Another constraint on possible configurations is the need to prevent gross arc-overs from the high voltage electrode to the metal chamber housing, which is at ground potential. The high voltages which typically appear in the chamber are in the 10 to 20 kilovolt range so that surface tracking along insulating materials is also a potential problem. Arc-overs which occur outside of the intended discharge region reduce the energy available for pumping of the laser medium and so reduce the UV pulse energy and the overall efficiency of the UV source. These arc-overs also cause erosion of chamber components other than the electrodes and so limit lifetime. Further, instabilities in arc-over phenomena translate directly to instability in the UV pulse energy which makes dose control difficult or impossible.

At PRF's in the kHz range it becomes important to replace the gas in the entire electrode region; not just in the region comprising the laser mode volume. This is because the lifetime of ions produced during one discharge is sufficiently long to cause downstream arcing during the next discharge if the gas is not swept entirely out of regions containing a high electric field. Simply having fresh gas in the laser region for successive pulses is insufficient to guarantee consistent pulse energy and beam properties. Correspondingly, Cymer has enhanced its gas flow design to allow higher gas flow velocities which are necessary to satisfy both of the requirements: namely, fresh gas in the laser region for each successive pulse, and no leftover ionized gas in the downstream, high electric field region.

Cymer has designed a laser to achieve aerodynamic stability at the gas flow velocity needed to clear the high-electric-field electrode region between laser pulses, and which minimizes blower system electrical power demand and centrifugal stress on the cross-flow fan. The materials used in construction of the critical electrode region are fully fluorine compatible and do not distort the electric field in the main discharge area. This design performs reliably and repeatably at 1 kHz PRF, and also has been designed to be manufacturable in large quantities.

4. PERFORMANCE MEASUREMENTS

An extensive series of spatial, spectral and temporal measurements has been made on the laser output beam at 1 kHz PRF. Also, measurements of gas flow velocities and levels of turbulence, before and after chamber modifications, were performed using a fast response hot-wire anemometer capable of resolving velocity changes on a time scale of the order of 200 μS.

Figure 1 shows the hot-wire anemometer measurement of turbulence in the region just downstream of the main discharge location, with and without flow modifications. Note that enhancing gas flow has reduced the turbulence level by a factor of ~3, based on the peak-to-peak velocity excursions, and allowed arc-free operation of the laser at 1kHz PRF with linear power scaling. Figure 2 shows average power as a function of PRF from 100 Hz to 1000 Hz.

Cymer's 5000 series lasers have been designed to have three configurations, making them suitable for a wide range of DUV microlithographic applications. There is a broadband (~ 300 pm) version, a "partially" line narrowed version (< 100 pm) for scanner applications and a fully line-narrowed version (<0.8 pm) for stepper applications. Figure 3 summarizes the general specifications of the different versions.

Pulse energy stability is of particular importance for dose control. As can be seen in figure 4, the 3σ value of pulse energy fluctuation is 5% with a 50 pulse window. Note that this leads to a dose variation of less than $\pm$ 0.5%.

The output pulse, shown in figure 5, has a FWHM duration of ~ 15 nS. The peak power during the pulse is 0.5 MW which, at the optical interface plate results in a power density of approximately 0.7 MW / cm^2. The full width of the optical pulse, after which 95% of the energy has been delivered, is 75 nS. Methods are known for increasing the pulse width and decreasing the peak power, to minimize optical damage.

5. LASER SYSTEM LAYOUT

Cymer's 5000 series lasers are constructed in a modular form so that service and maintenance actions are facilitated. In addition to the laser chamber itself, there are ten (10) other main modules. These are: (1) the mounting frame, (2) optical interface plate, (3) system controller, (4) gas handling, (5) water cooling, (6) AC distribution, (7) high voltage power supply, (8) pulse power , (9) laser resonator, and (10) wavelength control modules. The laser can be configured to operate on 208V, 3ϕ, 60 Hz or 380V, 3ϕ, 50 Hz line-frequency electrical power. Cymer's 5000

product series lasers are housed in a cabinet which is illustrated in figure 6. There are many safety features, such as a complete set of interlocks, in addition to the modules listed above. Figure 7 summarizes the 5000 series design standards. The required utility hook-ups, in addition to electrical, are: (a) air exhaust ventilation at 100 cfm; (b) cooling water at 7.5 liters/min.; (c) the gases, (nitrogen and helium); and (d) the laser gases (krypton, neon, fluorine).

6. CONCLUSIONS

Cymer has successfully engineered a 1 kHz PRF laser chamber which is central to its new 5000 series product. This new generation of laser products is ideally suited to the rapidly developing DUV lithography market, both in terms of performance and because they meet world-wide design and safety requirements.

7. ACKNOWLEDGMENTS

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8. REFERENCES

1. W. N. Partlo, R. L. Sandstrom, I.V. Fomenkov, P. Das, "Low cost of ownership KrF excimer laser using a novel pulse power and chamber configuration," *SPIE, Optical/Laser Microlithography VIII,* Vol. 2440-06, 1995.

ELS-5000 Development - Core Technology

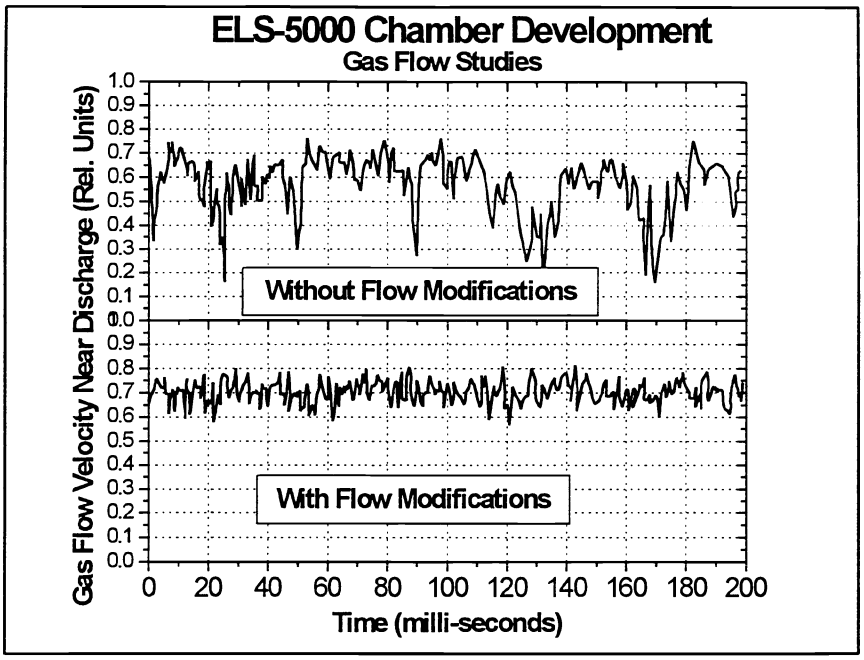


Figure 1 - Chamber Flow Velocity Measurements

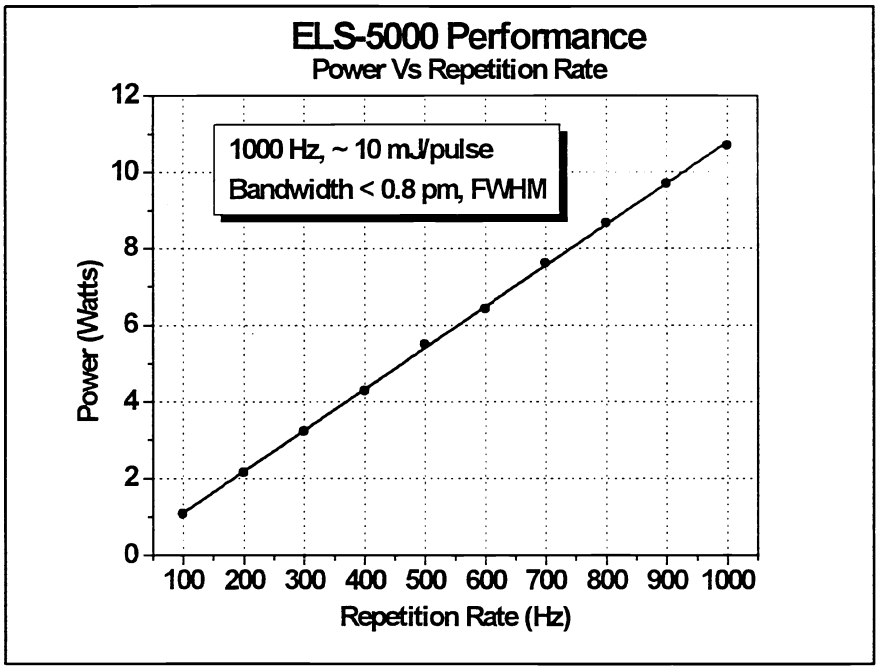
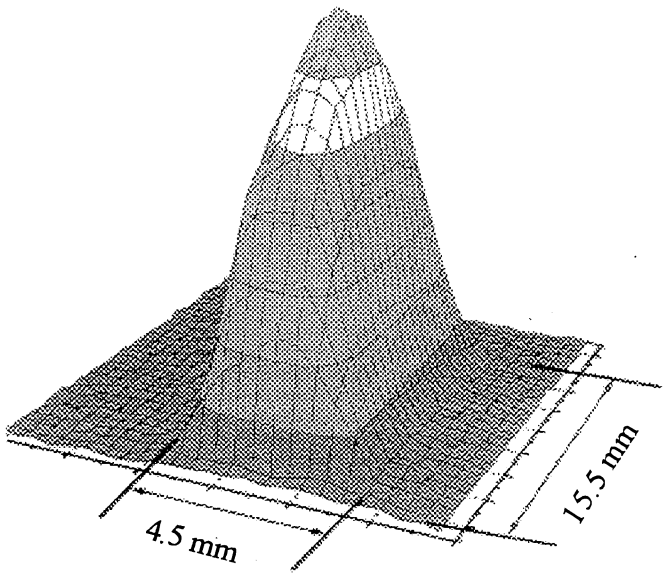


Figure 2 - Average Power Scaling as a Function of PRF. (E=10.4 mJ)

Figure 3 - ELS-5000 Series - General Specifications

Beam Profile - Partially Line Narrowed
Measured At Laser Output



- Three Configurations
 - Broadband
 - Partially Narrowed
 ($\Delta\lambda < 100$ pm)
 - Fully Narrowed
 ($\Delta\lambda \sim 0.8$ pm)

- Power
 - 15 W, broadband or partial
 - 10 W, fully narrowed

- Repetition Rate
 - 1000 Hz, Max.

- Integrated Energy Stability
 (50 pulse wind.)
 - $< \pm$ 1%, All Configurations

- Gas Life
 - 100 M pulses, 5 days

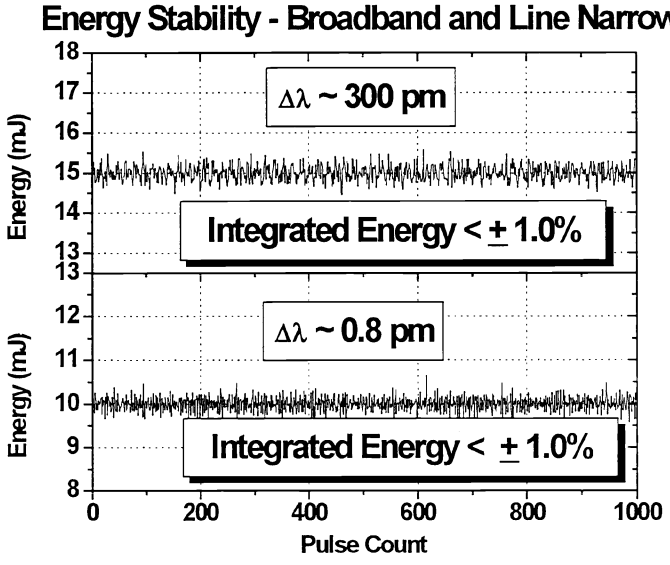


Figure 4 - Pulse Energy Stability Data

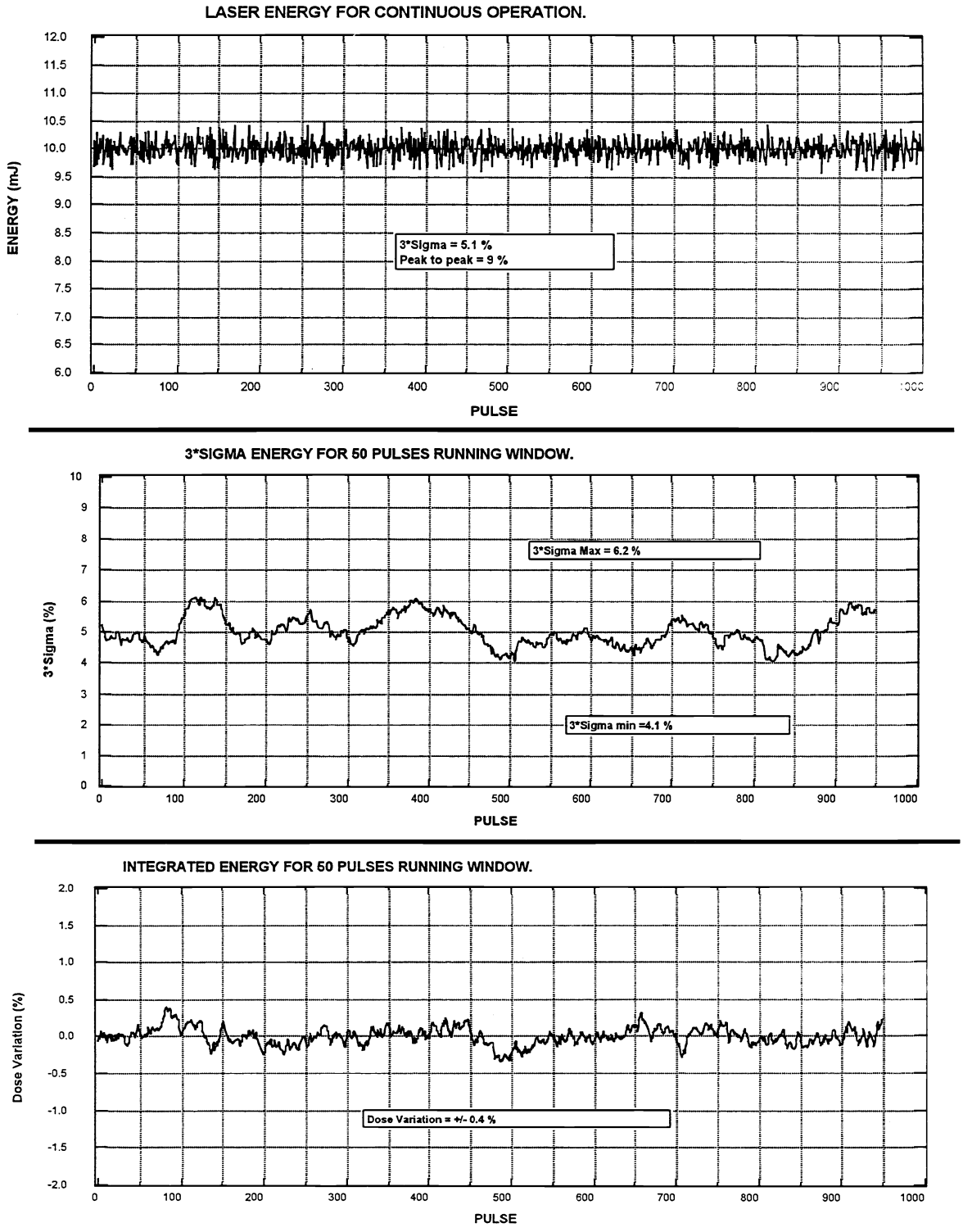


Figure 5 - Laser Output Pulse Characteristics

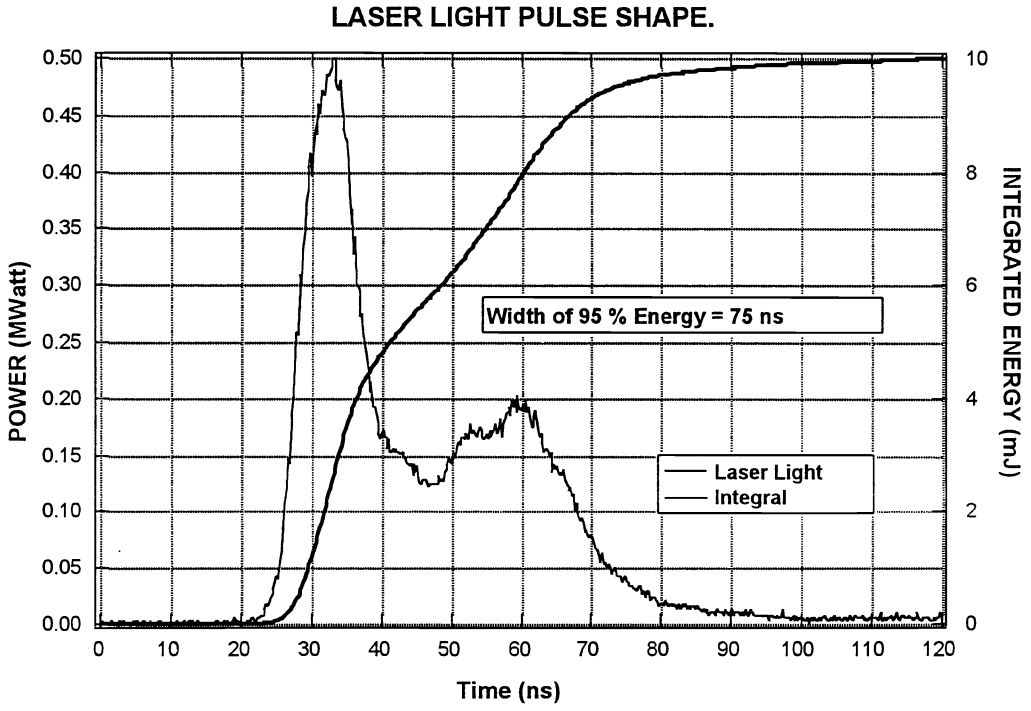
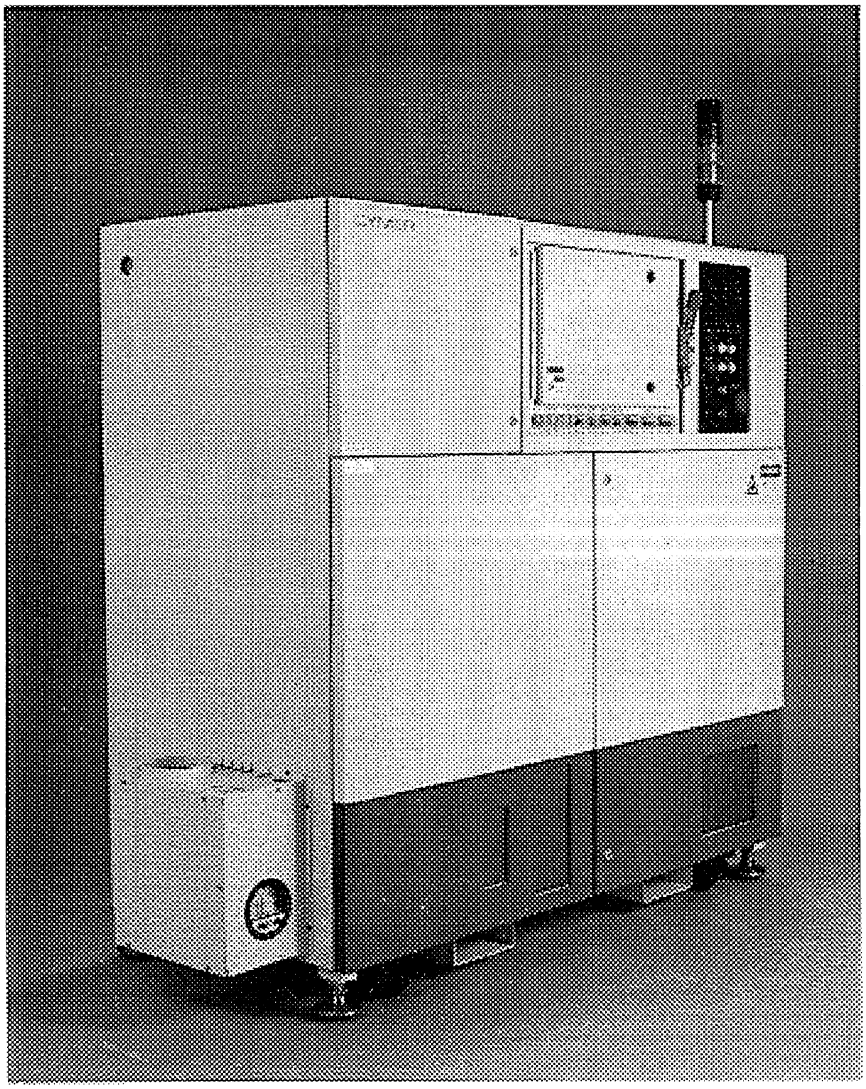


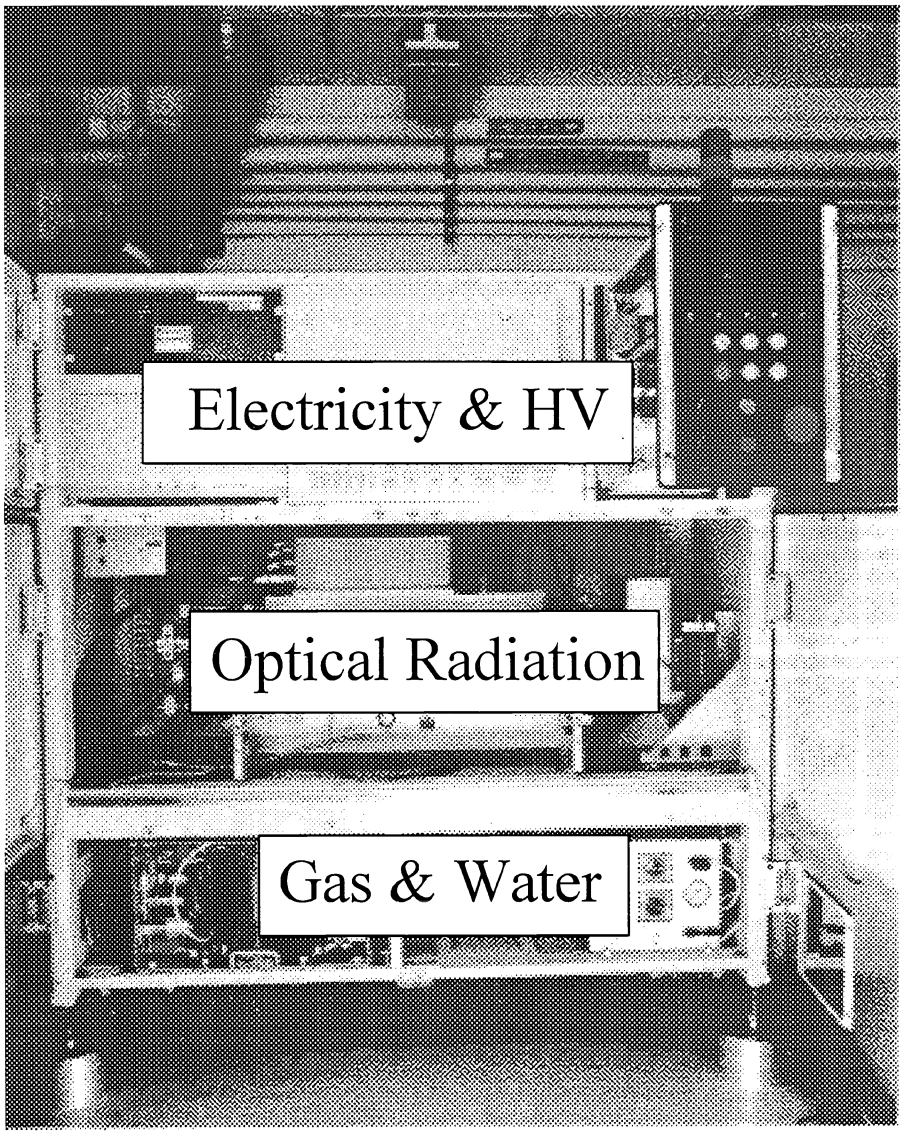
Figure 6 - ELS-5000 Series - Design



1. Modular Construction - Designed for high volume production. In Fact, 90% of Laser Modules are Designed & Manufactured Outside of Cymer.
2. Well Developed Core Technology - Incorporates existing laser chamber, solid-state pulsed power and bandwidth control technology. This minimizes risks associated with new products.
3. Configurable & Expandable - May be configured or expanded with numerous options. For example, stepper/scanner beam delivery can be directly mounted on laser enclosure. However, service area has been minimized.
4. Design Standards - Meets several international industry design and safety standards for world-wide installation.

Figure 7 - ELS-5000 Design Standards

1. S2-93 - Semiconductor Industry Safety Guidelines
2. SEMI F15 - Semiconductor Industry Tracer Gas
3. FCC Part 15A - Telecommunication Industry Standards
4. FDA/CDRH - Radiation Standards
5. ASME - Standard for Laser Chamber
6. 89/392/EEC Machinery
7. 89/336/EEC EMC
8. EN 60204 Equipment Safety
9. EN 50082-2 Electromagnetic
10. EN 55011 RFI
11. EN 60825 Radiation
12. Customer Specific



Separation of Utilities In Three Different Compartments Helps Conform to Safety Standards